PREFACE

The following is the fifth annual progress report prepared as part of the Central Valley Project Improvement Act Instream Flow Investigations, a 7-year effort which began in February, 1995. Title 34, Section 3406(b)(1)(B) of the Central Valley Project Improvement Act, P.L. 102-575, requires the Secretary of the Interior to determine instream flow needs for anadromous fish for all Central Valley Project controlled streams and rivers, based on recommendations of the U.S. Fish and Wildlife Service (FWS) after consultation with the California Department of Fish and Game (CDFG). The purpose of this investigation is to provide reliable scientific information to the U.S. Fish and Wildlife Service Central Valley Project Improvement Act Program to be used to develop such recommendations for Central Valley rivers.

The fieldwork described herein was conducted by Ed Ballard, Mark Gard, Erin Sauls, Rick Williams, Mike Morse, Susan Boring and John Kelly.

To those who are interested, comments and information regarding this program and the habitat resources of Central Valley rivers are welcomed. Written comments or information can be submitted to:

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INTRODUCTION

In response to substantial declines in anadromous fish populations, the Central Valley Project Improvement Act requires the doubling of the natural production of anadromous fish stocks, including the four races of chinook salmon (fall, late fall, winter, and spring), steelhead trout, and white and green sturgeon. In December 1994, the USFWS, Ecological Services, Instream Flow Assessments Branch prepared a study proposal to use the Service's Instream Flow Incremental Methodology (IFIM) to identify the instream flow requirements for anadromous fish in selected streams within the Central Valley of California. Subsequently, as discussed in our first annual report, the Sacramento, lower American and Merced Rivers were selected for study. In February 1998, the USFWS, Fish and Wildlife Office, Energy, Power and Instream Flow Assessments Branch prepared an updated study proposal. The updated study proposal added other streams, principally Butte Creek, to the above three selected for study. The studies on these rivers have been and will continue to be closely coordinated with study efforts being conducted by CDFG.

The Sacramento River study is a seven-year effort to be concluded in September, 2001. Specific goals of the study are to determine the relationship between streamflow and physical habitat availability for all life stages of chinook salmon (fall-, late fall-, winter-runs) and to identify flows at which redd dewatering and juvenile stranding conditions occur. The instream flow requirements for white and green sturgeon may also be studied; however, the inclusion of these species depends upon the availability of resources and sufficient data to enable identification of the habitats used by them. The study components include: 1) compilation and review of existing information; 2) consultation with other agencies and biologists; 3) field reconnaissance; 4) development of habitat suitability criteria (HSC); 5) study site selection and transect placement; 6) hydraulic and structural data collection; 7) construction and calibration of reliable hydraulic simulation models; 8) construction of habitat models to predict physical habitat availability over a range of river discharges; and 9) preparation of draft and final reports. The FY99 Scope of Work (SOW) identified study tasks to be undertaken. These included: field reconnaissance (study component 3); study site selection, transect placement, and hydraulic and structural data collection (study components 5 and 6); construction of hydraulic models (study component 7); and continuing the development of HSC (study component 4).

The lower American River study was a one-year effort which culminated in a March 27, 1996 report detailing the methods and results of this effort. This report was submitted to CDFG for enclosure in their final report on the lower American River. Subsequently, questions arose as to which of the chinook salmon spawning HSC criteria used in the March 27, 1996 report would be transferable to the Lower American River. As a result, additional field work was conducted in FY97, culminating in a supplemental report submitted to CDFG on February 11, 1997. As a result of substantial changes in the Lower American River study sites from the January 1997 storms, a second round of habitat data collection and modeling was begun in April 1998. Data collection for this effort was completed in February 1999 and a final report will be prepared by March 2000.

The Merced River study was a 1.5 year effort which culminated in a March 19, 1997 report detailing the methods and results of this effort. This report was submitted to CDFG for enclosure in their final report on the Merced River.

The Butte Creek study is a 2 year effort which will start with collection of spring-run chinook salmon spawning habitat suitability criteria during the last week of September 1999.

The following sections summarize project activities between October, 1998 and September, 1999.

SACRAMENTO RIVER

Field Reconnaissance and Study Site Selection

Field reconnaissance in FY99 investigated potential study sites between Battle Creek and Deer Creek where two-dimensional (2-D) habitat modeling will be undertaken for fall-run chinook salmon spawning. Some of these sites may also be used for habitat modeling of chinook salmon rearing. The following section describes the methods employed and the results of FY99 reconnaissance and study site selection efforts for this species.

Fall-run chinook salmon spawning habitat

During FY99, we followed up on the ranking of spawning areas in our FY97 annual report. In December 1998, we conducted a reconnaissance of the ten top ranked sites in Segments two and three[1] to determine their viability as study sites. Each site was evaluated based on morphological and channel characteristics which facilitate the development of reliable hydraulic models. Also noted were riverbank and floodplain characteristics (e.g. steep, heavily vegetated berms or gradually sloping cobble benches) which might affect our ability to collect the necessary data to build these models. For the sites selected for modeling, the landowners along both riverbanks were identified and temporary entry permits were sent, accompanied by a cover letter, to acquire permission for entry onto their property during the course of the study.

After reviewing the field reconnaissance notes and considering time and manpower constraints, six study sites were selected for modeling in Segments two and three: 1) Five Fingers Riffle; 2) Blackberry Riffle; 3) Osborne Riffle; 4) Upper Bend Riffle; 5) Jellys Ferry; and 6) Mudball Riffle. These six sites are those receiving the heaviest use by spawning fall-run salmon in Segments two and three.

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[1] As discussed in the FY95 annual report, we have divided the Sacramento River study area into six stream segments, based on hydrology and other factors: Colusa to Butte City (Segment 1); Deer Creek to Red Bluff Diversion Dam (Segment 2); above Lake Red Bluff to Battle Creek (Segment 3); Battle Creek to Cow Creek (Segment 4); Cow Creek to ACID (Segment 5); and ACID to Keswick (Segment 6). Segment 1 addresses green and white sturgeon, while the other segments address chinook salmon.

White sturgeon spawning habitat

On October 1, 1998, we used the Broad-Band Acoustic Doppler Current Profiler (ADCP) and underwater video equipment to perform a reconnaissance of known and potential sturgeon spawning locations in the Sacramento River between Colusa and Butte City to determine the suitability of substrates, depths and velocities at these locations for white sturgeon spawning, based on the habitat suitability criteria we previously developed. Our reconnaissance identified several candidate sites, but limited water clarity limited our abilities to evaluate the substrate; light levels were insufficient to identify substrates in depths greater than 16-17 feet. Substrate assessment in this reach would have to be conducted during a limited time of year. Further reconnaissance would be necessary to determine during what time of year this reach of the Sacramento River has the best water clarity, and if water clarity is good enough during such a time to characterize substrate in this reach with our underwater video equipment.

Transect Placement (study site setup)

Fall-run chinook salmon spawning habitat

The modeling of fall-run chinook salmon spawning in Segments two and three will be accomplished using two-dimensional modeling. The 2-D model uses as inputs the bed topography and cover of a site, and the water surface elevation at the bottom of the site, to predict the amount of habitat present in the site. The 2-D model avoids problems of transect placement, since the entire mesohabitat unit can be modeled. The 2-D model also has the potential to model depths and velocities over a range of flows more accurately than PHABSIM because it takes into account upstream and downstream bed topography and bed roughness, and explicitly uses mechanistic processes (conservation of mass and momentum), rather than Manning's n and a velocity adjustment factor. Other advantages of 2 -D modeling are that it can explicitly handle complex habitats, including transverse flows, across-channel variation in water surface elevations and flow contractions/expansions. The model scale is small enough to correspond to the scale of microhabitat use data with depths and velocities produced on a continuous basis, rather than in discrete cells. The 2-D model does a better job of representing patchy microhabitat features, such as gravel patches. The data can be collected with a stratified sampling scheme, with higher intensity sampling in areas with more complex or more quickly varying microhabitat features, and lower intensity sampling in areas with uniformly varying bed topography and uniform substrate and cover. Bed topography and substrate/cover mapping data can be collected at a very low flow, with the only data needed at high flow being water surface elevations at the top and bottom of the site and the flow and edge velocities for validation purposes. Only limited velocity data is required for validation purposes. In addition, alternative habitat suitability criteria, such as measures of habitat diversity, can be used.

Study sites were established in August 1999. The study site boundaries (top and bottom) were selected to coincide with the top and bottom of the boundaries of the heavy spawning use areas delineated by Kurt Brown (USFWS) and Carl Waller (CDFG) on aerial photos. These were based on their personal observations during the course of aerial surveys.

For each study site, a transect has been placed at the top and bottom of the site. The bottom transect will be modeled with PHABSIM to provide water surface elevations as an input to the 2-D model. The Five Fingers site has two bottom transects - one on the main channel and one on the side channel portion of the site. The upstream transect will be used in calibrating the 2-D model - bed roughnesses are adjusted until the water surface elevation at the top of the site matches the water surface elevation predicted by PHABSIM. The upstream transect will also be used to determine the distribution of flow across the upstream boundary as an input to the 2-D model. Transect pins (headpins and tailpins) were marked on each river bank above the 30,000 cfs water surface level using rebar driven into the ground and/or lag bolts placed in tree trunks. Survey flagging was used to mark the locations of each pin.

Hydraulic and Structural Data Collection

Chinook salmon spawning habitat

During FY98 we completed the collection of hydraulic and structural data for all of the spawning sites between Keswick Dam and Battle Creek. However, after conducting the initial hydraulic modeling during FY99, it was determined that additional water surface elevations were needed at several sites to adequately calibrate the models. Water surface elevations were collected at a flow of 26,106 cfs at Hawes Hole transects 1-6 in December 1998. Water surfaces elevations were collected at all transects in Lower and Upper Lake Redding and Salt Creek sites at a flow of 6,580 cfs in October 1998 and at a flow of 14,900 cfs in November 1998. Water surface elevations were also collected in the right channel of Posse Grounds transects 1-8 in February 1999 at a flow of 25,100 cfs and in March 1999 at a flow of 14,365 cfs.

Vertical benchmarks (lagbolts in trees) were established and water surface elevations collected in August 1999 at a flow of 10,000 cfs at all of the fall-run chinook salmon spawning sites between Battle Creek and Deer Creek. Velocity sets were collected on the Blackberry Island Site transects and a discharge was measured on the Five Fingers Riffle side channel during August 1999 as well at a flow of 10,000 cfs. In addition, the vertical benchmarks were tied together at Osborne, Bend Bridge, Mudball and Jellys Ferry sites.

Chinook salmon rearing habitat

Hydraulic and structural data collection, which began in March 1998, continued through FY99. The data collected at the inflow and outflow transects include: 1) water surface elevations (WSELs), measured to the nearest .01 foot at a minimum of three significantly different stream discharges using standard surveying techniques (differential leveling); 2) wetted streambed elevations determined by subtracting the measured depth from the surveyed WSEL at a measured flow; 3) dry ground elevations to points above bankfull discharge surveyed to the nearest 0.1 foot; 4) mean water column velocities measured at a mid-to-high-range flow at the points where bed elevations were taken; and 5) substrate and cover classification at these same locations and also where dry ground elevations were surveyed. Data collected between the transects include: 1) bed elevation; 2) northing and easting (horizontal location); 3) cover; and 4) substrate. These parameters are collected at enough points to characterize the bed topography, substrate and cover of the site.

The collection of water surface elevations at high, medium and low flows was completed with the measurement of low flow (approximately 6,000 cfs) water surface elevations at all sites. Additional high-flow (approximately 22,000 cfs) water surface elevations were also collected for sites 61/63 and 130. In addition, for sites which do not include the entire Sacramento River flow, discharge measurements were collected at a low-range flow (approximately 6,000 cfs) at Sites 96, 81, 80, 61/63, and 52, and at a mid-range flow (approximately 9,500 cfs) at Site 130. Depth and velocity measurements in portions of the transects with depths greater than three feet were made with the ADCP, while depths and velocity measurements in shallower areas were made by wading with a wading rod equipped with a Marsh-McBirney[R] model 2000 or a Price AA velocity meter.

Underwater video equipment and an electronic distance meter were used to determine the substrate and cover along the deeper portions of the transects, with the shallow and dry portions determined visually. The underwater video equipment consists of two cameras mounted on a 75 pound bomb at angles of 45 and 90 degrees. The 75 pound bomb is raised and lowered from our boat using a winch. Two monitors on the boat provide the views from the cameras. A grid on the 90 degree camera monitor calibrated at one foot above the bottom is used to measure the substrate and cover. Dry bed elevation data collection along the upper and lower transects was completed for all sites in FY99. To date, dry/shallow and deep substrate and cover data along the transects has been collected for all sites, with the exception of Salt Creek and Upper and Lower Lake Redding.

We have used two techniques to collect the data between the top and bottom transects: 1) for areas that are dry or shallow (less than three feet), bed elevation and horizontal location of individual points are obtained with a total station, while the cover and substrate are visually assessed at each point; and 2) in portions of the site with depths greater than three feet, the ADCP is used in concert with the total station to obtain bed elevation and horizontal location. Specifically, the ADCP is run across the channel at 50 to 150-foot intervals, with the initial and final horizontal location of each run measured by the total station. Our initial procedure to determine the water surface elevation of each run was as follows: 1) a water surface elevation profile down the site was determined using the level and the electronic distance meter (used to measure the distance down the site associated with each water surface elevation measured with the level); 2) the distance measured along each run by the ADCP, in concert with the initial and final horizontal locations, was used to compute the horizontal location (northing and easting) of each point along the run; and 3) the initial and final locations of each run was used to determine the distance down the site of each run, so that the water surface elevation of each run could be determined from the water surface elevation profile. However, subsequently we found that it was more efficient to directly measure the water surface elevation of each ADCP run. The water surface elevation of each run is then used together with the depths from the ADCP to determine the bed elevation of each point along the run. Velocities at each point measured by the ADCP will be used to validate the 2-D model. To validate the velocities predicted by the 2-D model for shallow areas within a site, depth, velocities, substrate and cover measurements were collected along the right and left banks within each site by wading with a wading rod equipped with a Marsh-McBirney[R] model 2000 or a Price AA velocity meter. The horizontal locations and bed elevations were determined by taking a total station shot on a prism held at each point where depth and velocity were measured. A minimum of 25 representative points were measured along the length of each side of the river per site. To date, validation velocities have been collected for all sites, with the exception of Salt Creek and Upper and Lower Lake Redding.

For the collection of the deep substrate and cover data for the first several sites, the initial and final locations of each deep bed elevation run were located using the previously-measured horizontal angle and slope distance, and marked with buoys. The underwater video and electronic distance meter were then used to determine the substrate and cover along each run, so that substrate and cover values can be assigned to each point of the run. However, subsequently it was determined that it is more efficient to collect the deep substrate and cover data immediately following the completion of the deep bed elevation data collection for a site, with buoys placed prior to the collection of the deep bed data and used during the collection of the deep substrate and cover data.

By determining the horizontal location of the head and tail pins of the transects at the spawning sites and collecting cover data on these transects, we have used all of the points on these transects to determine at least part of the bed topography and cover/substrate of these sites. To date, we have collected the dry and shallow bed elevation/horizontal location/substrate/cover data for all sites, with the exception of Salt Creek and Upper and Lower Lake Redding; this data will be collected after the boards have been removed at the ACID dam. Deep bed elevation/horizontal location/substrate/cover data has been collected for all sites, with the exception of parts of sites 112 and 15/17; collection of this data will require flows in the range of 13,000 to 15,000 cfs.

Hydraulic Model Construction and Calibration

All of the data for the spawning sites between Keswick Dam and Battle Creek has been compiled and checked. PHABSIM data decks have been created and hydraulic calibration has been completed for all spawning sites between Keswick Dam and Battle Creek. Final decks have been prepared to simulate spawning habitat for all spawning sites between Keswick Dam and Battle Creek, awaiting the completion of habitat suitability criteria. A final report on the above hydraulic modeling will be completed in October 1999.

Habitat Suitability Criteria (HSC) Development

Spawning

<u>Methods</u>

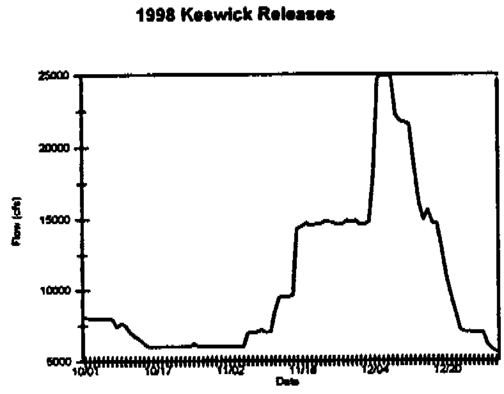
We attempted to locate fall and winter-run chinook salmon redds in shallow and deep water. We searched for shallow redds on foot and by boat. For both fall and winter-run chinook salmon, all of the active redds (those not covered with periphyton growth) within a given mesohabitat unit were measured. Data for shallow redds were collected from an area adjacent to the redd which was judged to have a similar depth and velocity as was present at the redd location prior to redd construction. This location was generally about two to four feet upstream of the pit of the redd; however it was sometimes necessary to make measurements at a 45 degree angle upstream, to the side, or behind the pit. The data were almost always collected within six feet of the pit of the redd. Depth was recorded to the nearest 0.1 ft and average water column velocity was recorded to the nearest 0.01 ft/s. Substrate was visually assessed for the dominant particle size range (i.e., range of 1-2"). Substrate embeddedness data were not collected because the substrate adjacent to all of the redds sampled was predominantly unembedded.

Location of redds in deep water was accomplished by boat using underwater video. Base aerial photos provided by CDFG showing the areas where winter-run chinook salmon redds have been observed in past years were used in locating the primary mesohabitat units where surveys were conducted. When searching for redds in deep water using underwater video, a series of parallel runs with the boat upstream within a mesohabitat unit was performed. After locating a redd in deep water, substrate size was measured using underwater video directly over the redds. Depth and water velocity was measured over the redds using the ADCP. The location of all redds was recorded with a Global Positioning System (GPS) unit, so that we could ensure that redds were not measured twice. All data were entered into spreadsheets for eventual analysis and development of Suitability Indices (HSC).

Surveys for shallow and deep fall-run chinook salmon redds were conducted November 16-19, 1998 in an attempt to collect depth, velocity and substrate data. However, during this period, the flows were rising and continued to rise throughout the remainder of the fall-run chinook salmon spawning period (Figure 1). Sacramento River flows (releases from Keswick Reservoir) ranged 5,989-14,727 cfs from October 9 through November 20. As a result, no further attempts to locate redds was attempted during 1998. Fall-run spawning HSC data collection will be completed during the 1999 fall-run spawning season.

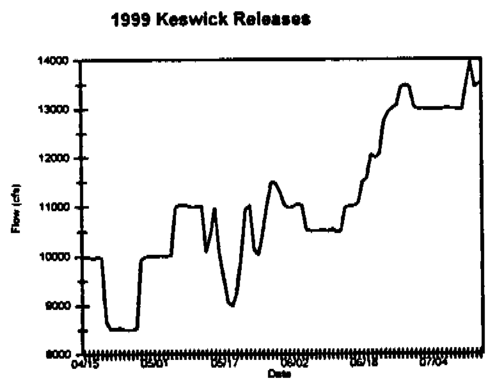
Depth, velocity and substrate data were collected on winter-run chinook salmon redds on June 8-11, June 22-25, and July 12-15, 1998. Sacramento River flows (releases from Keswick Reservoir) varied considerably, from 8,496 to 13,959 cfs (Figure 2), from the initiation of winter-run spawning in mid-April through the end of sampling. Unfortunately, this adds a measure of

Figure 1



uncertainty to HSI criteria to be developed from this data, since we can not be certain that the depths and velocities measured were similar to those during redd construction. Given the low population numbers of winter-run, it will likely be necessary to use data from this year despite the uncertainty in the data. To date, we have collected HSI data on 44 winter-run redds. It appears increasingly unlikely that we will be able to collect enough winter-run spawning data to develop HSC criteria. However, it is likely that we will be able to collect data on enough winter-run redds (55 observations) to determine if fall-run spawning criteria can be transferred to winter-run salmon. The effort to collect spawning HSC data for the winter-run will continue for the 2000 through 2001 spawning seasons, river conditions permitting.

Figure 2



Due to high turbidity and widely fluctuating flows (5,301 to 29,860 cfs) from mid-January through mid-April, it was impossible to collect any late fall-run HSC data. This chinook race spawns during the peak of the winter/early spring storm season (January through mid-April) when river flows are often very high and erratic. As a result, it appears increasingly unlikely that late fall-run spawning criteria can be developed in this study. The effort to collect spawning HSC data for the late fall-run will continue for the 2000 through 2001 spawning seasons, river conditions permitting.

Results

Data from only two fall-run chinook salmon redds were collected in FY99, both located in deep water. Due to the changing flow conditions between the start of fall-run spawning and the date of data collection, this data will not be used in developing HSC criteria. Numerous redds were observed in water less than three feet deep (too shallow for ADCP operation) in Lower Lake Redding, but strong current conditions in that area precluded data collection. Twenty-two mesohabitat units were sampled (one Side Channel (SC) Riffle, eight Bar Complex (BC) riffles, three Flat Water (FW) Runs, four Bar Complex Runs, one BC Pool, two FW Glides, one FW Pool, and two SC Pools).

Data were collected on a total of 17 winter-run chinook salmon redds (8 shallow and 9 deep redds). Thirty-two mesohabitat units were sampled (four SC Riffles, one SC Pool, one SC Run, four BC Runs, two BC Pools, one BC Glide, nine BC Riffles, five FW Glides, two FW Riffles, two FW Runs, and one FW Pool). The above mesohabitat units are all of the areas where winter-run redds have been observed between Keswick Dam and Battle Creek in past aerial redd surveys. However, winter-run redds were only found in ten mesohabitat units (one FW Pool, two FW Riffles, three FW Glides, two BC Riffles, one BC Run, and one SC Riffle, Table 1). As mentioned above, no data were collected for the late fall-run.

Table 1
1999 Winter-run Redd Locations

Location	Number of Redds
Upper Lake Redding	1
Bridge Riffle	2
Posse Grounds (Mesohabitat Units 135 and 136)	7
Mesohabitat Unit 133 (River Mile 297.3)	1
Mesohabitat Unit 132 (River Mile 297)	1
Mesohabitat Unit 123 (River Mile 296.3)	2
Mesohabitat Unit 111 (River Mile 294.9)	1
Tobiasson Riffle	1
Mesohabitat Unit 83 (River Mile 289.8)	1

Rearing

HSC data were collected for chinook salmon fry and juveniles (YOY) on November 2-4, 1998 May 17-20, 1999 and July 20-23, 1999. Our intent was to sample one week every three months. However, due to high flows and turbidity, we were unable to sample during the first three months of 1999. Keswick releases were approximately 6,000 cfs during the November 1998 surveys, approximately 9,000 cfs during the May 1999 survey, and approximately 13,000 cfs during the July 1999 survey. As in previous years, data were collected in areas adjacent to the bank. However, greater emphasis was placed on scuba surveys of deeper water mesohabitat areas due to the limited amount of data collection in these areas in previous years.

When conducting snorkeling surveys adjacent to the bank, one person would snorkel along the bank and place a weighted, numbered tag at each location where YOY chinook salmon were observed. The snorkeler would record the tag number, the cover code[2] and the number of individuals observed in each 10-20 mm size class on a PVC wrist cuff. Cover availability in the area sampled (percentage of the area with different cover types) and the length of bank sampled (measured with the electronic distance meter) would also be recorded. Another individual would retrieve the tags, measure the depth and mean water column velocity at the tag location, and record the data for each tag number. Depth was recorded to the nearest 0.1 ft and average water column velocity was recorded to the nearest 0.01 ft/s. An adjacent mean water column velocity was also measured within two feet[3] on either side of the tag where the velocity was the highest. This measurement was taken to eventually provide the option of using an alternative habitat model which considers adjacent velocities in assessing habitat quality. Adjacent velocity can be an important habitat variable as fish, particularly fry and juveniles, frequently reside in slow-water habitats adjacent to faster water where invertebrate drift is conveyed. Both the residence and adjacent velocity variables are important for fish to minimize the energy expenditure/food intake ratio and maintain growth. Data taken by the snorkeler and the measurer were correlated at each tag location and entered into a spreadsheet for eventual analysis and development of HSC.

Free dives were made during the November 1998 survey to locate juvenile salmon in deep water. Starting with the May 1999 survey, when conducting scuba surveys of deep water mesohabitat areas, a rope was anchored longitudinally upstream through the area to be surveyed

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[2] If there was no cover elements (as defined in Table 2) within one foot horizontally of the fish location, the cover code was 0 (no cover).

[3] Two feet was selected based on a mechanism of turbulent mixing transporting invertebrate drift from fast-water areas to adjacent slow-water areas where fry and juvenile salmon reside, taking into account that the size of turbulent eddies is approximately one-half of the mean river depth (Terry Waddle, USGS, personal communication), and assuming that the mean depth of the Sacramento River is around four feet (ie., four feet x ½ = two feet).

Table 2
Cover Coding System

Cover Category	Cover Code[4]
no cover	0
cobble	1
boulder	2
fine woody vegetation (< 1" diameter)	3
branches	4
log (> 1' diameter)	5
overhead cover (< 2' from water surface)	7
undercut bank	8
aquatic vegetation	9
rip-rap	10

to facilitate upstream movement by the divers and increase diver safety. Two divers entered the water at the downstream end of the rope and proceeded along the rope upstream using climbing ascenders. One diver concentrated on surveying the water below and to the side, while the other diver concentrated on surveying the water above and to the side. When a juvenile salmon was observed, a weighted buoy was placed by the divers at the location of the observation. The cover code and the number of individuals observed in each 10-20 mm size class was then recorded on a PVC wrist cuff. Cover availability in the area sampled (percentage of the area with different cover types) and the length of river sampled (measured with the electronic distance meter) was also recorded. After the dive was completed, individuals in the boat retrieved each buoy and measured the water velocity and depth over that location with the ADCP. For each set of data collected using ADCP for a juvenile fish observation, the average depth and velocity are considered the depth and velocity, while the maximum velocity is considered the adjacent velocity.

[4] In addition to these cover codes, we have been using composite cover codes; for example, 4/7 would be branches plus overhead cover.

LOWER AMERICAN RIVER

As a result of the 115,000 cfs flood releases made into the lower American River in January of 1997, considerable morphological changes have occurred in many areas of the river including some of our previous study sites. As a result, CDFG inquired into the possibility that we collect additional hydraulic and structural data, and develop new spawning habitat models for fall-run chinook salmon on the lower American River.

We decided to run both PHABSIM and the 2-D habitat modeling program funded by the U.S.G.S. office in Fort Collins, Colorado to allow for additional comparisons of the 2-D model to PHABSIM. The 2-D model uses as inputs the bed topography and substrate of a site, and the water surface elevation at the bottom of the site, to predict the amount of habitat present in the site. The 2-D model will be run for each of the five study sites described in the FY98 annual report. The downstream-most PHABSIM transect will used as the bottom of the site, to provide water surface elevations as an input to the 2-D model. The upstream-most PHABSIM transect will be used as the top of the site, to calibrate the 2-D model - bed roughnesses are adjusted until the water surface elevation at the top of the site matches the water surface elevation predicted by PHABSIM. This transect will also be used to determine the distribution of flow across the upstream boundary as an input to the 2-D model.

Hydraulic and Structural Data Collection

The data collected at each PHABSIM transect include: 1) water surface elevations (WSELs), measured to the nearest .01 foot at a minimum of three significantly different stream discharges using standard surveying techniques (differential leveling); 2) wetted streambed elevations determined by subtracting the measured depth from the surveyed WSEL at a measured flow; 3) dry ground elevations to points above bankfull discharge surveyed to the nearest 0.1 foot; 4) mean water column velocities measured at a mid-to-high-range flow at the points where bed elevations were taken; and 5) substrate classification at these same locations and also where dry ground elevations were surveyed. Data collected for the 2-D model include: 1) bed elevation; 2) northing and easting (horizontal location); and 3) substrate. These parameters are collected at enough points to characterize the bed topography and substrate of the site. Hydraulic and structural data collection began in April 1998 and was completed in February 1999.

Additional water surface elevations at a flow of approximately 3,000 cfs were measured at all five sites in November and December 1998. Velocity sets were also completed for all transects at a flow of approximately 3,000 cfs. Depth and velocity measurements in portions of the transects with depths greater than three feet were made with the ADCP, while depths and velocity measurements in shallower areas were made by wading with a wading rod equipped with a Marsh-McBirney^R model 2000 or a Price AA velocity meter. In addition, substrate data was completed for all transects. Substrate data in dry and shallow areas was determined by direct observation, while substrate in deeper areas was determined using underwater video.

We have used two techniques to collect the data for the 2-D model: 1) for areas that are dry or shallow (less than three feet), bed elevation and horizontal location of individual points are obtained with a total station, while the substrate is visually assessed at each point; and 2) in portions of the site with depths greater than three feet, the ADCP is used in concert with the total station to obtain bed elevation and horizontal location. Specifically, the ADCP is run across the channel at 50 to 150-foot intervals, with the initial and final horizontal location of each run measured by the total station. A water surface elevation profile down the site is determined using the level and the electronic distance meter (used to measure the distance down the site associated with each water surface elevation measured with the level). The distance measured along each run by the ADCP, in concert with the initial and final horizontal locations, are used to compute the horizontal location (northing and easting) of each point along the run. The initial and final locations of each run are used to determine the distance down the site of each run, so that the water surface elevation of each run can be determined from the water surface elevation profile. The water surface elevation of each run is then used together with the depths from the ADCP to determine the bed elevation of each point along the run. Velocities at each point measured by the ADCP will be used to validate the 2-D model[6]. At a later time, the initial and final locations of each run are located using the previously-measured horizontal angle and slope distance, and marked with buoys. The underwater video and electronic distance meter are then used to determine the substrate along each run, so that substrate values can be assigned to each point of the run. By determining the horizontal location of the head and tail pins of all of the PHABSIM transects, we can use all of the points on these transects to determine at least part of the bed topography and substrate of these sites. Deep bed elevation/horizontal location data for all five sites was completed in FY98. In FY99, we completed the collection of the dry and shallow data and the substrate data for the deep bed locations for all sites.

Habitat Suitability Criteria (HSC) Development

Spawning

Methods

Surveys for shallow and deep fall-run chinook salmon redds were conducted December 14-17, 1998 in an attempt to collect depth, velocity and substrate data. We searched for shallow redds on foot. All of the active redds (those not covered with periphyton growth) within a given site were measured. Data for shallow redds were collected from an area adjacent to the redd which was judged to have a similar depth and velocity as was present at the redd location prior to redd construction. This location was generally about two to four feet upstream of the pit of the redd; however it was sometimes necessary to make measurements at a 45 degree angle upstream, to the side, or behind the pit. The data were almost always collected within six feet of the pit of the

[6] Velocities measured on the PHABSIM transects will also be used to validate the 2-D model.

redd. Depth was recorded to the nearest 0.1 ft and average water column velocity was recorded to the nearest 0.01 ft/s. Substrate was visually assessed for the dominant particle size range (i.e., range of 1-2"). Substrate embeddedness data were not collected because the substrate adjacent to all of the redds sampled was predominantly unembedded. Location of redds in deep water was attempted by boat using underwater video. When searching for redds in deep water using underwater video, a series of parallel runs with the boat upstream within a mesohabitat unit was performed. After locating a redd in deep water, substrate size was measured using underwater video directly over the redds. Depth and water velocity was measured over the redds using the ADCP. The location of all redds was recorded with the total station, so that we could ensure that redds were not measured twice. All data were entered into spreadsheets for eventual analysis and development of Suitability Indices (HSC).

Results

A total of 100 shallow and deep redds were sampled at the Sailor Bar site and a total of 89 shallow redds were sampled at the Above Sunrise site[7]. A total of 15 deep water redds were observed were observed at the Sailor Bar site. No deep water redds were observed at the Above Sunrise site. Visibility was marginal (around three feet) while using the underwater video and may have affected the number of redds that were observed in deep water. Furthermore, the surveys were conducted during the latter part of the fall-run chinook salmon spawning season when many of the redds constructed earlier in the season were likely recolonizing with algae, making recognition difficult. However, the 189 redd observations should provide sufficient data to develop spawning habitat suitability criteria.

SALMOD

Jason Kent, a graduate student at Colorado State University, has applied the SALMOD salmon production model to the Sacramento River for his master's thesis. SALMOD will integrate the results of our Sacramento River instream flow studies and the instream flow studies currently being conducted by CDFG to link Keswick release flow rates and water temperatures with chinook salmon production in the Sacramento River. As a result, it will be possible to directly assess the effects of different Keswick release schedules on pre-smolt chinook salmon production.

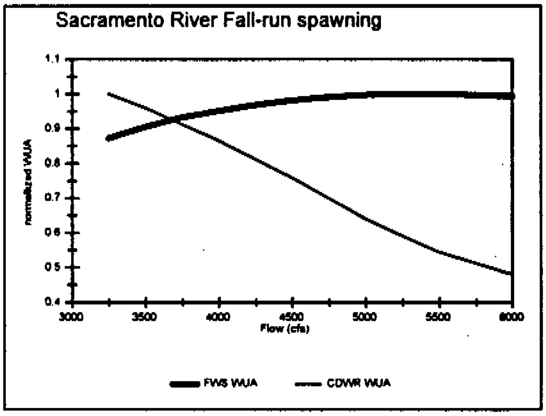
We provided Jason the results of our spawning habitat modeling for the spawning sites between ACID dam and Battle Creek, using preliminary habitat suitability criteria developed from our fall-run spawning habitat use observations to date, and preliminary juvenile habitat suitability criteria, for use in SALMOD. Figure 3 compares the results from CDWR's fall-run spawning habitat modeling for the Sacramento River between ACID dam and Cottonwood Creek, and the results of our preliminary habitat modeling, over the range of flows that are of most interest in regulating Sacramento River flows during the fall. The results have been normalized so that the

[7] Time constraints limited sampling to only these two sites.

highest value of WUA for each curve has a value of 1.0. The significant difference in results is due both to differences in habitat suitability criteria and a different approach in selecting habitat modeling sites[8].

In response to requests from resource agency personnel, we updated our calculations of the distribution of fall-run chinook salmon spawning in our study segments. The percentages in Table 5 are the average percent of fall-run redds from 1989-98 based on data from CDFG's aerial redd surveys. Based on Figure 3 and Table 5, we have concluded that we should model fall-run chinook salmon spawning habitat in Segments two and three, and thus initiated habitat modeling in these reaches during FY99. Specifically, we have already modeled fall-run spawning habitat in 45% of the spawning distribution (Segments four and five), and with adding Segments two and three, we will be modeling 87% of the spawning distribution of fall-run chinook salmon.

Figure 3



BUTTE CREEK

Habitat Suitability Criteria (HSC) Development

Spawning

We will begin collecting habitat suitability criteria data for spring-run chinook salmon spawning in Butte Creek during the last week of September 1999. We plan to sample Butte Creek from Centerville Head Dam to Parrot Phelan Dam.

[8] CDWR used a representative reach approach in selecting habitat modeling sites, while we located habitat modeling sites solely in areas which had historically received high spawning use.

Table 5
Distribution of Fall-run Chinook Salmon Spawning, 1989-98

Segment	Percent Spawning
6 (Above ACID)	7%
5 (ACID to Cow Creek)	36%
4 (Cow Creek to Battle Creek)	9%
3 (Battle Creek to upper end Lake Red Bluff)	27%
Lake Red Bluff	2%
2 (Red Bluff Diversion Dam to Deer Creek)	15%
Below Deer Creek	4%

PHABSIM MODEL VALIDATION

We published a paper (Appendix A) in the April 1999 issue of the Canadian Journal of Fisheries and Aquatic Sciences summarizing the results of our 1995-1996 CVPIA-funded studies on the lower American River and the Merced River. The paper presents results validating the PHABSIM-predicted habitat, based on the observed distribution of chinook salmon spawning.

APPENDIX A

GALLAGHER AND GARD 1999

Relationship between chinook salmon (*Oncorhynchus tshawytscha*) redd densities and PHABSIM-predicted habitat in the Merced and Lower American rivers, California

Sean P. Gallagher and Mark F. Gard

Abstract: An index of chinook salmon (*Oncorhynchus tshawytscha*) spawning habitat predicted using the physical habitat simulation system (PHABSIM) component of the instream flow incremental methodology was compared with redd densities and locations for sites in the Merced River, California, during 1996 and with redd numbers in sites in the Merced and Lower American rivers, California, from 1989 through 1996. Predicted weighted useable area (WUA) was significantly correlated with chinook salmon spawning density and location at five of seven sites in the Merced River. At the microhabitat level, in the Merced River during 1996, there was a significant relationship between chinook salmon redd location and predicted WUA. Cells with more WUA in the Merced River tended to have more redds. At the mesohabitat level, there was a significant relationship between redd density and predicted WUA in both rivers. Transect areas in the Merced River with higher predicted WUA had more redds. Sites with higher numbers of redds had more predicted WUA. Significant correlations between predicted WUA and spawning locations increase confidence in the use of PHABSIM modeling results for fisheries management in the Merced and Lower American rivers as well as in other rivers.

Résumé : On a comparé un indice des frayères du quinnat (*Oncorhynchus tshawytscha*), établi au moyen du système de simulation de l'habitat physique (PHABSIM) de la méthode incrémentielle de l'écoulement en rivière, aux densités et aux emplacements des nids dans des sites de la rivière Merced (Californie) en 1996 et au nombre de nids dans des sites des rivières Merced et Lower American (Californie) de 1989 à 1996. L'aire utilisable pondéré prévue était significativement corrélée avec la densité et la localisation des quinnats en fraye à cinq des sept sites de la Merced. À l'échelle du microhabitat, dans la Merced en 1996, il y avait une relation significative entre l'emplacement des nids de quinnat et l'aire utilisable pondérée prévue. Les cellules de la Merced où l'aire utilisable pondérée était plus grande tendaient à renfermer plus de nids. À l'échelle du mésohabitat, il y avait une relation significative entre la densité des nids et l'aire utilisable pondérée prévue dans les deux rivières. Les transects de la Merced où l'aire utilisable pondérée prévue était plus grande renfermaient plus de nids. Les sites renfermant le plus de nids comportaient une aire utilisable pondérée prévue plus importante. Les corrélations significatives entre l'aire utilisable pondérée prévue et les emplacements de la fraye accroissent la confiance qu'on peut avoir dans les résultats de la modélisation fondée sur le PHABSIM pour la gestion des pêches dans la Merced et la Lower American ainsi que dans d'autres rivières.

[Traduit par la Rédaction]

Introduction

Relationships between fish population levels and physical habitat simulation system (PHABSIM) (Milhous et al. 1989) habitat predictions have had mixed results (Conder and Annear 1987; Shirvell 1989). While PHABSIM is used extensively for predicting potential habitat with changes in stream flow, validation of relationships between model predictions and fish population levels has received little attention (Reiser et al. 1989). By applying life stage specific habitat suitability criteria for depth, velocity, substrate, and cover, PHABSIM predicts depth and velocity across a channel and combines them with substrate or cover into a habitat index known as weighted useable area (WUA) (Bovee 1982; Milhous et al. 1989). The WUA output is generally simulated for river reaches over a range of stream flows. The PHABSIM operates under the assumption that if physical habitat is a limiting factor, the quality and quantity of available habitat (i.e., WUA) for a limiting life stage during a limiting flow event are directly related to fish population levels. This implies that fish will use higher quality habitat (identified by PHABSIM) more often than habitat of lower quality and that the amount of habitat should translate into fish production (Bovee 1982). Users of PHABSIM assume that WUA predicted by PHABSIM is a consistent measure of quality and quantity of habitat. The validity of this assumption has long been debated (Orth and Maughan 1982; Mathur et al. 1985; Conder and Annear 1987; Orth 1987; Scott and Shirvell

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Table 1. Merced River study site locations and number of transects at each site.

Site	River km	No. of transects
1	83.7	5
2	74.0	5
3	73.5	3
4	73.2	2
5	72.1	6
6	70.5	3
7	69.8	4

1987; Castleberry et al. 1996). Conder and Annear (1987) suggested that the relationship between WUA and fish population levels is unique to each stream and that PHABSIM predictions should not be used before relationships are shown.

We examined the relationship between chinook salmon (*Oncorhynchus tshawytscha*) spawning and WUA predictions from PHABSIM at the microhabitat and mesohabitat levels in the Merced River, California, and at the mesohabitat level in the Lower American River, California. We compared chinook redd density and locations with predicted WUA cell by cell, by transect, and at the mesohabitat level using an in-river approach. The purpose of this study was to test the consistency of WUA as an index of habitat at different spatial and temporal scales when transects were placed in sites known to be heavily used for spawning.

Study sites

The study was part of investigations conducted by the U.S. Fish and Wildlife Service and the California Department of Fish and Game to identify instream flow requirements for anadromous fish in streams within the Central Valley of California, pursuant to the Central Valley Project Improvement Act. The rivers selected for study were chosen because they are major regulated Central Valley streams for which additional investigations are needed to identify instream flow requirements.

The Merced River, located in the San Joaquin River basin, and the Lower American River, located in the Sacramento River basin, drain 2693 and 5376 km^2, respectively, along the western flank of the Sierra Nevada Mountains in California (Fig. 1). The Merced and Lower American rivers have a mean annual flow of 18.7 and 106 m^3/s, respectively. Both rivers have hatcheries that contribute to fall-run chinook salmon production and are located at the upstream limit to anadromous fish migration. The Merced River portion of this study was conducted in a 16-km reach directly below Crocker–Huffman Dam, while the American River portion of the study was conducted in a 9-km reach 1.5 km below Nimbus Dam (Fig. 1). The two study reaches were chosen because they were the portions of the Merced and American rivers with the highest use by spawning fall-run chinook salmon during the past decade (CDFG 1994, 1996; USFWS 1996, 1997). Seven sites were selected in the Merced River and 10 sites in the American River for measuring chinook salmon redd microhabitat characteristics and modeling available habitat.

Materials and methods

Field measurements

To model chinook spawning WUA, we collected physical and hydraulic data along transects for input into the hydraulic and habitat simulation models within PHABSIM using procedures outlined in Trihey and Wegner (1981). We placed transects in the Merced and Lower American River study sites across the optimal spawning areas based on substrate size and past redd distributions. Table 1 lists the river location and number of transects at each site on the Merced River. Twenty transects, two at each study site, were placed on the Lower American River. Lateral cell boundaries were established across each transect systematically or where differences in bed elevations, water velocity, or substrate composition occurred. Cell boundaries were established halfway between adjacent measurement points, so that the center of each cell was at a measurement point. The average number of cells, cell area, cell width, and distance between transects for the Merced and American rivers are shown in Table 2. Dominant substrate was visually assessed using a modified Brusven index (Platts et al. 1983). We collected cell depths, velocities, and substrate data at flows of 11.95–13.36 m^3/s for the Merced River during October 1996 and 70.8–84.9 m^3/s for the American River during August 1996. We measured water surface elevations and discharges at three or four flows for each site. These flows ranged from 28.3 to 113.3 m^3/s for the American River during August–October 1995 and from 2.32 to 32.7 m^3/s for the Merced River during August–October 1996 (USFWS 1996, 1997).

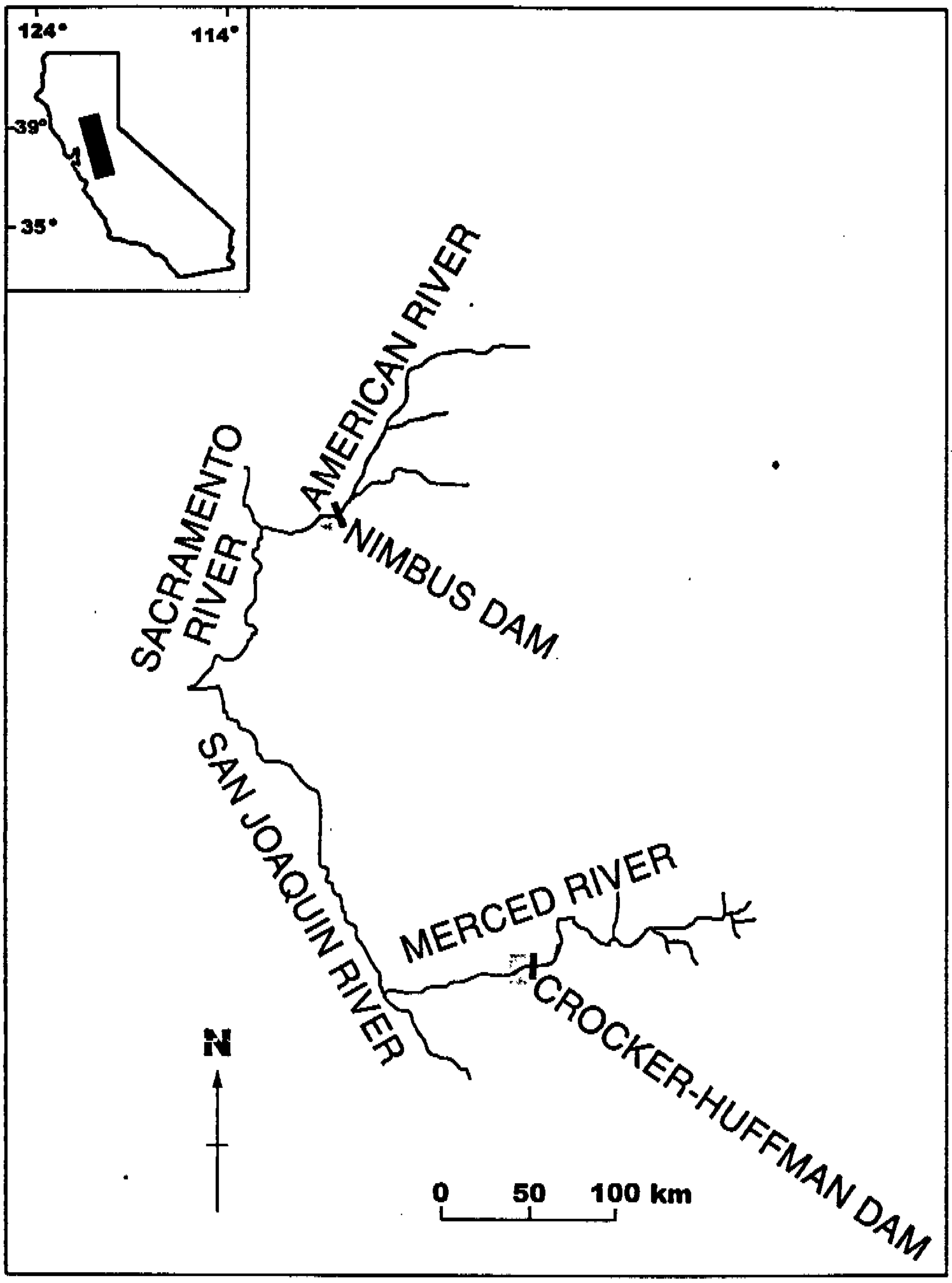
To develop chinook salmon spawning habitat suitability criteria, we collected depth, velocity, and substrate data on 186 fall-run chinook salmon redds in the Merced River between 12 and 14 November 1996 at a flow of 7.79 m^3/s and on 218 fall-run chinook salmon redds on the Lower American River on 6 and 7 November 1996 at a flow of 78.6 m^3/s (Table 3). Flows were stable in both rivers from the beginning of the spawning period through the dates of data collection. All newly constructed redds (redds without periphyton) at each site were measured. Depth and water column velocity data were collected 0.5 m upstream of the redd pot, where hydraulic conditions were assumed to be similar to those at the redd location prior to construction. Dominant substrate was visually assessed in the tail spill using a modified Brusven index (Platts et al. 1983). We used horizontal surveying to determine the locations of 151 redds relative to our transects at the seven studies sites in the Merced River.

Habitat modeling

Average water column velocities, water surface elevations, riverbed elevations, cell substrate categories, and site discharges were entered into PHABSIM to create hydraulic models for each transect. Hydraulic data were calibrated following procedures in Milhous et al. (1989). We used the calibrated decks for both rivers in IFG4 to simulate hydraulic characteristics for each site at the average flows present during the peak of fall-run chinook salmon spawning for 1989–1996 (Table 4).

Habitat suitability criteria (HSC curves) are used within PHABSIM to translate hydraulic and structural elements of rivers into indices of habitat quality (Bovee 1994). We used the redd measurements from the Merced and Lower American rivers to create stream-specific HSC curves (Gard 1998). We used the HABTAE program and the Merced River specific HSC curves to predict WUA for comparison with the redd locations and densities at 7.79 m^3/s. To calculate total cell WUA, we predicted compound suitability for each cell and multiplied this by the area that each cell represented. The WUA calculated for each cell was summed to produce WUA by transect, and transect WUA at each site was summed to produce site estimates. We also used the HABTAE program and the Merced and Lower American River specific HSC

Fig. 1. Location of the Merced and Lower American rivers, California. Shaded areas are the study reaches used to evaluate the relationship between chinook salmon spawning and PHABSIM-predicted habitat index relationships.



curves to predict WUA for each site for the average flows in Table 4.

Data analysis

To examine microhabitat WUA and spawning density correlations for the Merced River in 1996, we compared predicted WUA for each cell along each transect with redd locations and density. We analyzed the data this way for each site and then pooled the entire data set to increase the sample size. We examined the data to determine if, in the cells where we found redds, PHABSIM predicted less WUA than required for a redd, assuming a minimum nest area of 4.5 m^2 (minimum size reported by Burner 1951). If PHABSIM predicted <4.5 m^2 of WUA for a cell containing a redd, we treated the cell as having no WUA. To determine if there was a relationship between chinook salmon spawning density and predicted WUA at the mesohabitat level in the Merced River in 1996, we compared redd density with WUA by transect and by site. Merced River site 1 included two transects that crossed two split channels, and site 2 had two transects crossing three split channels. For the transect-level analysis, the portion of each transect crossing a split channel was treated as a separate transect. All data were compared using the nonparametric gamma correlation coefficient. The gamma statistic is preferable to the Spearman R statistic when the data contain many tied observations (Stat Soft, Inc. 1995). The cell-by-cell data had many tied observations.

To examine the relationship between mesohabitat WUA and redd numbers from 1989 through 1996 in the Merced River and from 1991 through 1995 in the Lower American River, we conducted an analysis of covariance (ANCOVA). Redd numbers for the period 1989–1996 were from the California Department of Fish and Game (C. Mayotte, California Department of Fish and Game, Fresno, Calif., unpublished data). The dependant ANCOVA variable was

Table 2. Average, minimum, maximum, and SD for the number of cells, cell width, cell area, and distance between transects used for PHABSIM data collection and modeling on the Merced and Lower American rivers.

	No. of cells		Cell width (m)		Cell area (m^2)		Distance between transects (m)	
	Merced	American	Merced	American	Merced	American	Merced	American
Average	38	47	1.1	2.6	43.9	278	26.6	34
Minimum	24	34	0.08	0.02	0.08	7.4	11	12
Maximum	58	59	7	11	315.5	1743	77.4	75
SD	8	8.5	0.58	1.4	25.4	237	15.6	20

Table 3. Average, minimum, maximum, and SE for hydraulic characteristics of chinook salmon redds measured in the Merced (n = 186) and Lower American (n = 218) rivers during 1996.

	Depth (m)		Velocity (m/s)		Substrate size (cm)	
	Merced	American	Merced	American	Merced	American
Average	0.4	0.7	0.6	0.7	5–10	5–7.5
Minimum	0.1	0.2	0.14	0.2	2.5–5	2.5–5
Maximum	0.7	1.8	1.26	1.25	10–15	7.5–12.5
SE	0.007	0.02	0.01	0.01	0.18	0.08

number of redds, while the categorical variable was year and the covariate was WUA. Statistical significance was accepted at the 0.05 probability level.

Results

Five of the seven sites on the Merced River during 1996 showed significant relationships between WUA and redd location and density at the microhabitat level (Table 5). Two sites showed no relationship between redd location and simulated WUA at the microhabitat level. When the data for all sites were combined, the relationship between WUA and redd location and density was significant at the microhabitat level ($\gamma = 0.471$, $P < 0.000001$, n = 1060). The PHABSIM predicted zero WUA for 11% of the cells observed to have one or more redds. When we set the WUA equal to zero for cells with <4.5 m^2 of predicted area per redd, 34% of the cells with spawning had zero predicted WUA. With the data thus modified, a significant relationship between cell WUA and redd density and location was still shown ($\gamma = 0.524$, $P < 0.000001$, n = 1060). Ninety-eight percent of cells with no predicted WUA and 90% of the cells with <4.5 m^2 of predicted WUA had no redds.

Mesohabitats with more redds had more WUA. Areas represented by transects with higher WUA had significantly more redds in the Merced River during 1996 ($\gamma = 0.321$, P = 0.01, n = 34). Transects with higher predicted WUA had more redds than transects with lower WUA (Table 5). Because Merced River site 1 was very close to the dam and data points from this site were outliers, we excluded it from some analyses. Excluding site 1, the relationship was stronger ($\gamma = 0.495$, $P = 0.0007$, n = 27). At the mesohabitat level (i.e., sites) in the Merced River during 1996, there was a significant relationship between redd density and predicted WUA ($\gamma = 0.714$, $P = 0.02$, n = 7). Excluding site 1, the relationship was again stronger ($\gamma = 0.867$, $P = 0.01$, n = 6).

At the mesohabitat level in the Merced River, we found a significant relationship between the number of redds and WUA ($r^2 = 0.17$, $P = 0.0036$, n = 56) (Fig. 2) for the period 1989–1996. Excluding site 1 from the analysis strengthened this relationship ($r^2 = 0.38$, $P = 0.000016$, n = 48). Similarly, for the American River at the mesohabitat level for the period 1991–1995, we found a significant relationship between the number of redds observed and WUA ($r^2 = 0.40$, P = 0.000003, n = 50) (Fig. 3).

Discussion

Shirvell (1989) used regularly spaced transects to examine the relationship between PHABSIM predictions and chinook salmon spawning in Canada and concluded that PHABSIM incorrectly predicted the amount of habitat and locations of chinook salmon spawning. We placed our transects in sites known to be heavily used by spawning salmon and did not space transects uniformly. Rather, transects were spaced so that each transect was representative of the substrate size, riverbed slope, depths, and velocities within the length of river modeled by each transect. We found significant correlations between predicted WUA and chinook salmon spawning at the microhabitat and mesohabitat levels.

In the Merced River, we found a significant relationship between chinook salmon redds and predicted WUA in cells for five of seven sites. The lack of a significant relationship at the other two sites was likely due to low statistical power as a result of the small sample size of redds at these two sites (Table 5). PHABSIM predicted 11% of the cells where we observed redds as unuseable (WUA = 0 initially) and 34% of cells with redds had <4.5 m^2 of WUA. Nonetheless, even though some cells with redds were predicted as having no habitat, cells having WUA were used disproportionately more than cells having no WUA. Since most of the cells with WUA <4.5 m^2 did not have redds, the gamma coefficient was larger when WUA was set to zero for cells with WUA <4.5 m^2. Nineteen of the 39 cells where spawning was observed in habitat predicted as unuseable by PHABSIM had unsuitable substrate (i.e., too large or aquatic vegetation). The PHABSIM model simulates habitat for an area of river based on data collected along a transect perpendicular to the river. Substrate is variable within a streambed, and simply estimating it at a point may not accurately capture its char-

Table 4. Time period, average, minimum, maximum, and SE for daily average chinook salmon spawning river discharge (m^3/s) in the Merced and Lower American rivers.

	1989	1990	1991	1992	1993	1994	1995	1996
Merced								
Time period	22 Nov. – 31 Dec.	20 Nov. – 27 Dec.	14 Nov. – 31 Dec.	4 Nov. – 23 Dec.	26 Oct. – 17 Nov.	8–20 Nov.	24 Oct. – 7 Nov.	23 Oct. – 14 Nov.
Average	5.7	6.0	7.2	6.9	6.2	6.7	12.9	8.4
Minimum	5.4	5.4	6.9	6.1	5.4	6.0	11.0	7.6
Maximum	6.1	6.6	7.3	10.3	7.5	7.3	13.8	9.0
SE	0.03	0.04	0.02	0.2	0.1	0.1	0.2	0.1
American								
Time period	—	—	19 Oct. – 25 Nov.	3 Nov. – 4 Dec.	28 Oct. – 16 Nov.	27 Oct. – 16 Nov.	16 Oct. – 28 Nov.	—
Average	—	—	41.8	16.1	55.6	32.7	68.8	—
Minimum	—	—	27.3	14.9	49.6	19.2	66.5	—
Maximum	—	—	92.6	18.6	61.7	39.9	72.2	—
SE	—	—	0.5	0.02	0.2	0.5	0.03	—

Note: Redd count data were not available for 1989, 1990, and 1996 for the Lower American River.

acteristics between transects. Sampling above and below the transect in the cells to be represented by PHABSIM might improve the accuracy of the substrate component of predicted spawning habitat.

For the other instances where spawning occurred in cells that PHABSIM predicted as having little or no WUA, the absence of WUA was due to high predicted velocities (11 cells) or low depth (nine cells). Higher velocities have lower suitabilities, and in the calculation of WUA, cells with low HSC values for velocity have lower overall WUA predictions. We measured mean column velocities at redds of up to 124 cm/s, yet the criteria curves give this a low suitability value due to the infrequent occurrence of this velocity in our redd measurements. Of the cases where PHABSIM predicted no habitat due to depths with low suitability, two redds were in cells with depths <12 cm, the lowest depth at which we observed salmon spawning (Table 3). The others were due to the low HSC values for shallow depths, resulting in PHABSIM calculating lower habitat, similar to as discussed above for velocity.

Fish spawning in areas predicted as having little or no WUA based on PHABSIM-predicted depth or velocity may be due to (*i*) inaccuracies in PHABSIM's prediction of depths or velocities, (*ii*) variation in depth and velocity in a cell along the stream profile, (*iii*) saturated habitat conditions, (*iv*) chinook salmon spawning habitat being composed of more than depth, velocity, and substrate, or (*v*) low compound suitability of a cell. DeVries (1997) suggested that changes in bed topography due to repeated heavy spawning cause hydraulics in these areas to become quite complicated. Use of two-dimensional hydraulic and habitat models (Leclerc et al. 1995) may help address inaccuracies in habitat predictions resulting from complex hydraulics and from longitudinal variation in depth, velocity, and substrate. Vaux (1968) suggested that upwelling, associated with a concave streambed profile, is an important feature of chinook salmon spawning habitat. The PHABSIM cannot simulate these features. Vyverberg et al. (1996) found that substrate permeability was an important indicator of chinook salmon spawning use. We indirectly addressed permeability by only locating transects in high spawning use areas. Permeability could be directly addressed in PHABSIM by including it as a component of substrate. This would require measuring permeability at redd locations during criteria development and along transects.

An apparent lack of sufficient habitat resulting from low compound suitability is a result of treating WUA as the actual area of streambed available for spawning at a small scale. For example, a 5-m^2 area of stream with a compound suitability of 0.2 would have a WUA value of 1.0 m^2 and might be considered unsuitable, even though the area is used at a low frequency. In this case the calculated WUA may be interpreted as that, on average, two out of 10 such areas will have a redd. In contrast, an area of 1 m^2 with a compound suitability of 1.0 would also have a WUA of 1.0 m^2 and would also be considered unsuitable, and in fact is unsuitable, as the total area is <4.5 m^2. At a larger scale (i.e., at the transect or mesohabitat level) the areas with low compound suitability are combined such that the total number of redds corresponds to total WUA. Consistent with this conclusion, our results showed that the relationship between number of redds and WUA increased in strength with increased scale (i.e., the relationship at the mesohabitat level was stronger than at the transect and cell levels). Thus, at larger scales, WUA may be a good predictor of available spawning habitat.

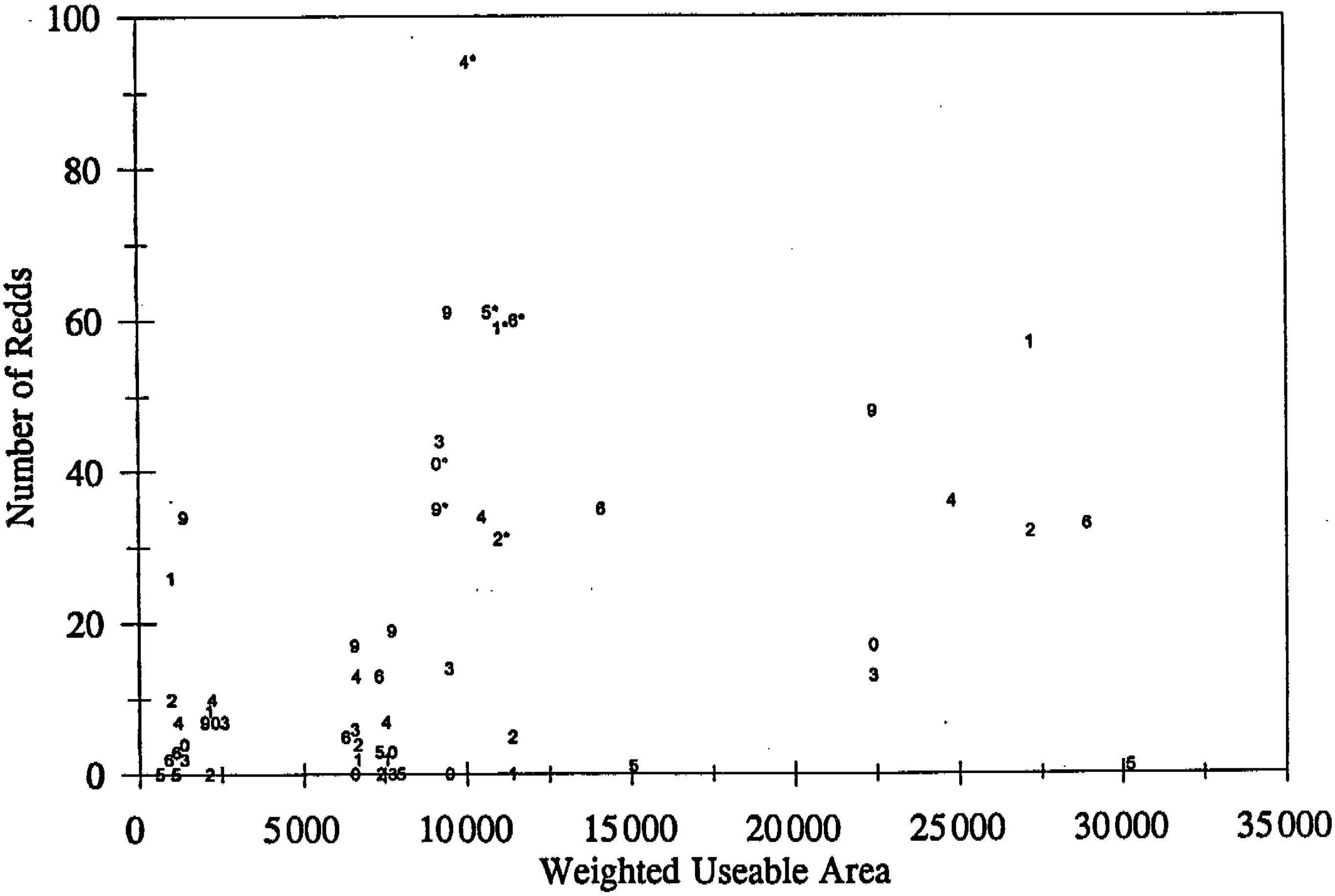
The results of our analysis of Merced River data at the transect and mesohabitat levels for 1996 (Table 5) and for multiple years (Fig. 2) suggested that the proximity of a site to the upstream limit for chinook salmon migration influences spawning numbers. Specifically, Merced River site 1 was located 0.2 km downstream of Crocker–Huffman Dam and had very high spawning levels, relative to the amount of WUA at the site. The aggregation of chinook salmon below this barrier increased the density of spawning above that which was expected based on the amount of WUA available. We observed redd superposition at this site and very little redd superposition at the other sites on the Merced River during 1996. The aggregation of chinook salmon below the dam lowered the ability of PHABSIM to predict the amount of spawning at this site, and thus the relationship between the number of redds and WUA was stronger when this site

Table 5. Merced River study site summary for 1996.

Site	Riffle area (m^2)	WUA (m^2)	No. of redds	γ cell WUA	P
1	4224.3	338.3	60	0.244	<0.02
2	6471.5	412.0	35	0.383	<0.001
3	1236.4	33.1	3	0.05	>0.50
4	980.7	26.2	2	0.03	>0.50
5	7402.2	844.4	33	0.166	<0.001
6	6547.1	214.1	13	0.329	<0.01
7	4061.7	184.3	5	0.189	<0.02

Note: Riffle area and WUA are calculated at a discharge of 7.79 m^3/s. γ cell WUA and P values are gamma correlation coefficients and statistical significance of the coefficient for relationships between redd location and WUA at each site on a cell-by-cell basis. Number of redds was the number used in the transect- and site-level analyses. Only 55 redds were used for site 1 in the cell-level analyses because we were unable to determine from our field data in which cell five of the redds were found, although we were able to determine in which transect they were.

Fig. 2. Redd numbers versus WUA for seven sites on the Merced River from 1989 to 1996. Asterisks indicate site 1. Numbers are the last digit of the year of the data (i.e., 9's are data from 1989, 1's are data from 1991, etc.).

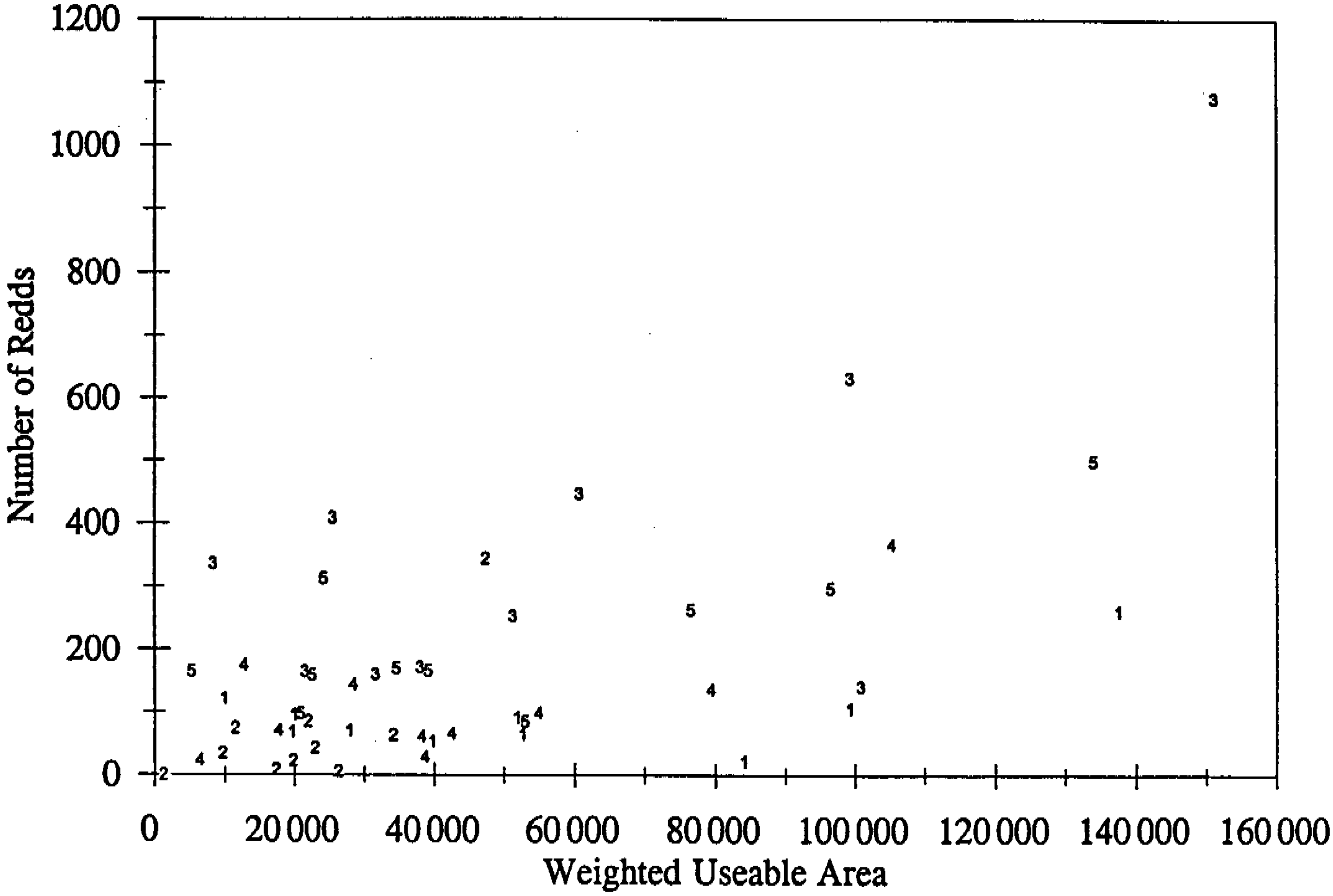


was excluded from the analysis. We did not observe this effect in the American River, either because the most upstream site was 1.5 km below the dam or because the effect was obscured because the most upstream site had the highest WUA.

Kondolf et al. (1996) evaluated the spawning gravel enhancement of the Merced riffle site 1 and found that gravels placed in this riffle were scoured out every 1.5 years and that the benefit to spawning salmon was questionable. Gravels were placed in this site again in 1996 prior to fall-run spawning (M. Cozart, California Department of Fish and Game, Merced River Hatchery). The placement of spawning gravels did not increase the available WUA above that of all other riffles (Table 5). Yet this may have influenced spawning, as all the gravels were fresh and clean. The amount of fine material in the substrate and the porosity of spawning gravels could be included in PHABSIM WUA calculations by incorporating them into the substrate component of habitat.

Conder and Annear (1987) stated that if habitat variables modeled by PHABSIM exhibit a strong influence on standing crop, WUA–density relationships may be valid. DeVries

Fig. 3. Redd numbers versus WUA for 10 sites on the Lower American River from 1991 to 1995. Numbers are the last digit of the year of the data (i.e., 9's are data from 1989, 1's are data from 1991, etc.).



(1997) stated that substrate followed by velocity are the most influential hydraulic and geomorphic features influencing spawning. For chinook salmon spawning in the Merced and Lower American rivers, depth, velocity, and substrate appear to be important habitat factors. Attempting to predict flow habitat induced chinook salmon population responses is complicated because much of their life is not spent in rivers. The positive correlations between flow-related WUA estimates and chinook salmon redds indicated by most of our results suggest that fish may respond to flow-related hydraulic improvements. However, without set flows and long-term monitoring, the effects of flow alterations on salmon populations in the Merced and Lower American rivers will remain unknown.

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